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Your Ref. : 200762/VRD

20 April 2001

PATENT APPLICATION NUMBER 0109656.9

The Patent Office confirms receipt of a request for grant of a patent, details of which have been recorded as follows :

Filing Date (See Note)	:	**19-APR-01**
Applicants	:	Bookham Technology plc
Description (No.of Sheets)	:	9
Claims (No.of Sheets)	:	3
Drawings (No.of Sheets)	:	4+4
Abstract	:	None
Statement of Inventorship (Form 7/77)	:	None
Request for Search (Form 9/77)	:	Yes
Request for Examination (Form 10/77)	:	None
Priority Documents	:	None
Translation of Priority Documents	:	None
Other Attachments Received	:	None

The application number included in the heading above should be quoted on all correspondence with The Patent Office.

Any queries on this receipt should be addressed to Janine Geran, tel. 01633 814570. All other enquiries should be directed to Central Enquiry Unit, tel. 0845 9 500 505.

Note : The above filing date is provisional and may need to be amended if the provisions of section 15(1) of the Patents Act 1977 are not met.

OPTICAL DEMULTIPLEXER

The invention relates to optical signal demultiplexers and particularly to such devices including a dispersive array integrated on a planar substrate.

Integrated chip optical demultiplexers are known including devices which have a plurality of opto/electric transducers such as photodiodes to provide output signals corresponding to the demultiplexed optical signals. When using a row of photodiodes to sense the output from a plurality of output channels, the optical signals of the output channels need to be separated to a spatial extent corresponding to the spacing of the photodiodes. Due to the limitation of small size of photo diode, the optical signals in the output channels need to be separated accordingly. If the optical array is formed by semiconductor waveguides the spatial separation of the optical output channels can be much closer than can be achieved for an array of photodiodes. Known proposals for such devices include detecting the output channels from the array in a plurality of output waveguides which collect the demultiplexed channels and deliver the light to output locations which are sufficiently spaced to match the array of photodiodes.

It is an object of the present invention to provide an improved optical signal demultiplexer in which the spatial separation of the output channels may be controlled by means other than diverging output waveguides.

The invention provides an optical signal demultiplexer integrated on a planar substrate comprising a dispersive array of optical paths of different optical path length on the substrate, said demultiplexer having an input focal position at which light may be input to the array and an output focal line at which output signals representing the demultiplexed signals are focussed, the demultiplexer including: a first set of reflectors located along the output focal line and arranged to respectively reflect each focussed output signal along a respective reflected path; and a second set of reflectors arranged on the planar substrate, each reflector

arranged in one of said reflected paths to reflect the reflected output signal incident thereon to a respective output location on the planar substrate.

Preferably the dispersive array is substantially symmetrical at opposite ends.

The first set of reflectors can comprise a plurality of plane mirrors. The second set of reflectors can comprise a plurality of concave mirrors, which can be parabaloid or arc mirrors. Preferably there is a single concave mirror in each reflective path, that is associated with each plane mirror. The ratio of the distance between the concave mirror and the plane mirror and the distance between the concave mirror and the output location can lie in the range of 0.5 to 2. The concave mirror is preferably located equidistant from the plane mirror and from the output location, by a distance equivalent to its focal length F_n.

The demultiplexer may include a plurality of light detectors located at the output locations so as to provide a plurality of output signals representing respectively the demultiplexed signals.

Preferably the light detectors are located on the integrated planar substrate.

The light detectors may comprise a line of photodiodes at one edge of the substrate. Light output from the demultiplexer has a narrow Gaussian dispersion characteristic. Preferably, each photodiode has a width which is greater than the width at the half height (3dB) level of the Gaussian characteristic such than a broad flat pass band is imaged by the concave mirror onto the photodiode. Where the photodiodes are used to convert optical digital signals to electrical digital signals, this broad flat pass band accomplishes this with less signal distortions than conventional flat band array waveguides since the flat part of the band can occupy more than 50% of the channel spacing without the –3dB loss caused by conventional flattening of the band.

The spacing of the output photodiodes along the edge of the chip can be in a manner designed to minimise RF crosstalk.

Alternatively, output photodiodes can be located anywhere on the chip in a manner such as to both minimise RF crosstalk and maximise space for RF amplification and transmission components. In one arrangement, eight photodiodes are arranged in two rows of four, the pitch of each row matching the pitch of a four channel RF amplifier mounted adjacent to the chip. The eight digital electrical outputs in this arrangement can be connected as eight differential pairs.

The demultiplexer can incorporate metal tracking, shaped tracking to provide RF passive waveguide components and metal pads for hybridisation of RF amplification components.

Preferably the dispersive array comprises a plurality of optical waveguides.

Preferably the direction of the waveguides is inclined inwardly towards each other at the input end of the array so that the directional axes of the waveguides at the input end intersect at the said input focal position.

Preferably a free light propagating region is provided on the substrate between the input end of the dispersive array and said input focal position.

Preferably the direction of the waveguides is inclined inwardly towards each other at the output end of the array so that the directional axes of the waveguides at the output end intersect. Alternatively the waveguides at the output end of the array are arranged parallel to each other.

The waveguides of the dispersive array may be parallel to each other at the input end of the array. Preferably a free light propagating region is provided between the output end of the dispersive array and the first set of reflectors.

Preferably the demultiplexer is formed as an integrated chip.

Preferably the demultiplexer includes a plurality of silicon on insulator waveguides.

The waveguides may comprise a plurality of rib or ridge waveguides.

Preferably the ends of the wave guides in the array terminate in part circular arcs at each end of the array.

For a better understanding of the present invention and to show how the same may be carried into effect, reference will now be made by way of example to the accompanying drawings, in which:

Figure 1 is a diagram of a prior art optical signal multiplexer using output waveguides;

Figure 2 is a view corresponding to that of Figure 1 but showing an embodiment of the present invention;

Figure 3 shows more detail of the location of channel output signals in use of the device of Figure 2; and

Figures 4 and 5 are schematic diagrams illustrating further embodiments of the invention.

In the schematic prior art arrangement shown in Figure 1, a dispersive waveguide array 11 consists of a plurality of curved waveguides 12. Each of the waveguides has a straight input section 15 and a straight output section 19. Line 13 indicates the junction between the straight input sections 15 and the curved sections 12. Similarly the line 14 indicates the junction between the curved sections and the straight output sections 19. In this case the input and output ends of the array 11 are symmetrical. The straight input sections 15 incline inwards towards each other so as to point to the focus position 17 at the end of the input waveguide 16.

Similarly the straight output sections 19 are inclined towards each other so as to form a focus in region 20 adjacent the entrance to an array of output waveguides 21. The geometry of the input and output ends of the array each form part of a similar Rowland circle arrangement. The input ends of the straight waveguide sections 15 lie on an arc forming part of a larger circle 22 having its centre coincident with the end 17 of the input waveguide 16. Point 17 lies on the circumference of an inner circle 23 having half the radius of the larger circle 22. Similarly at the output end of the array 11, the ends of the straight waveguide sections 19 terminate on an arc forming part of a larger circle 24 having its centre coincident with region 20 forming a focus for the output of the dispersive array. The output waveguides 21 are also arranged to terminate in an arc lying on the smaller inner circle 25 which has half the radius of the outer circle 24. Due to the dispersion within the array 11 being dependent on wavelength, the demultiplexed output channels are focussed on an arc of the circle 25 adjacent the output waveguides 21. At the input and output of the array 11, there is a free propagating region FPR in which light propagates freely. The channels are closely spaced at the focal line and are too closely positioned for effective detection by respective photodiodes in the output detectors 26. For this reason the array of output waveguides 21 detect the output channel images formed on circle 25 and transmit the optical signals to more spaced locations at the edge 27 of the chip where the spacing is sufficient to match the separate diode locations in the array of diodes 26.

In the first embodiment of the invention shown in Figure 2, similar reference numerals have been used for similar parts. The demultiplexer is formed as an integrated chip on a planar substrate. The substrate may be formed with silicon on insulator and the waveguides may be ridge waveguides of the type shown in US Patent 5757986. The array 11 is a dispersive array of ridge waveguides formed on the chip 30 with an input arrangement similar to that already described for Figure 1. In this case the dispersive array 11 is symmetric in that the waveguide regions 15 and 19 at opposite ends of the array are inwardly inclined in similar fashion and each terminate in an arc lying on part of the larger Rowland

circle 22 at the input end and a similar diameter Rowland circle 24 at the output end.

A first set of plane mirrors 31_a, 31_b, ... 31_n is arranged on an arc of the circle 25 at the end of the free propagation region, in fact corresponding closely to the position at which the input of the output waveguide 21 is located in Figure 1. Each plane mirror is formed for example by deep etched surfaces in the silicon substrate. Each plane mirror 31_a ... 31_n is arranged to reflect focussed light for a respective one of the plurality of channels transmitted via the waveguide array. The light incident on the reflectors in the first set of reflectors 31 is reflected through the bulk of the chip 30 onto a second set of curved mirrors 32 which are arranged to redirect light onto the output detectors 26. The inward inclination of the output waveguides 19, the location and angle of the mirrors 31_a ... 31_n, and the location and curvature of the concave mirrors 32_a ... 32_n are such as to focus the output light channels at the row of detectors 26 which are located at an edge 33 of the chip 30. The output detectors in this example comprise a row of photodiodes arranged to provide output signals corresponding to light detected in the output channels. With the arrangement in Figure 2, each curved mirror has a focal length F_n and is arranged at a distance F_n from its corresponding plane mirror in the first set of mirrors 31 and a distance FN from its corresponding output location on the row of detectors 26. The mirrors in the first set are referred to herein as turning mirrors, while the mirrors in the second set are referred to herein as re-imaging mirrors.

It will be understood that by using a set of turning mirrors in conjunction with a set of re-imaging mirrors it is possible to increase the spacing between the image of output channels, thereby enabling output channels to be detected by corresponding photodiodes in the array 26. The bandwidth of focussed channels is equivalent to the physical size (width) of the photodiodes. The main factor determining the frequency spacing is the physical spacing of the first mirrors. In the example shown in Figure 2, light is input to the input waveguide 16 through an optical fibre 34 along which the multiplexed output channels are transmitted. The

photodiodes 26 are arranged to provide output signals on electrical lines to further electrical circuitry.

Figure 3 shows more detail as to how one might locate the turning mirrors on the output Rowland circle 25. The demultiplexed signals form a plurality of channels extending between a "first" channel and a "last" channel as shown in Figure 3. The channel outputs are focussed on the arc of the Rowland circle 25 with the first and last channel being focussed at the opposite edges of the array where line C crosses the Rowland circle 25. The centre channel is focussed at the point where line A forms a tangent to the Rowland circle 25. These focussing points can be used to select the location and angle of the plane mirrors in the set of turning mirrors 31. The mirrors are chosen to be as wide as possible without blocking the light paths from adjacent mirrors, in order to maximise the bandwidth of the channels.

Figure 4 is a schematic diagram illustrating a further variant in accordance with the invention. Similar reference numerals have been used for similar parts as in Figure 2. Again, the array of ridge waveguides 11 forms a symmetrical dispersive array. A free propagating region FPR is located at each end of the array 11 and the ends of the waveguides forming the array 11 are tapered inwardly towards each other and terminate in an arcuate line forming part of the circumference of a large Rowland circle at the input end and at the output end. For the sake of clarity, the Rowlands circles are not shown in Figure 4. In this case, the plane mirrors in the set of reflectors 31 are located at differing angles. Thus, light incident on them from the respective channels is reflected along reflective paths of different directions to different locations on the chip 30. The second set of reflectors therefore comprise distributed concave mirrors, each arranged to pick up a reflected signal for one channel from its associated turning mirror in the set 31. This allows the channels to be directed onto photodiodes 26 which are arranged at spaced locations on opposing edges of the chip 30.

Figure 5 is a schematic diagram of another variant, once again in which the turning mirrors are located at differing angles on the output focal line. The curved reflectors in the second set 32 are again arranged at different locations on the chip 30, in the case of Figure 5 so as to direct light from individual output channels onto spaced apart photodiodes on one edge of the chip 30.

It will be appreciated that many different configurations are possible, Figures 2, 4 and 5 giving exemplary configurations only.

It will be understood that in the preceding examples, the use of first and second sets of reflectors in the optical output path allows the focussed image of the output channels to be at sufficiently remote positions to provide the required spacing between the channels to be picked up by the light detectors. The waveguides in the dispersive array may be arranged to maintain constant spacing between adjacent waveguides throughout their length along the array. In such a case, the input and output waveguides of the array may be straight and parallel with each other. The spacing and relocation of the output channel images enables light to be incident directly on photodiodes at convenient locations. For example, images for each output channel can be incident directly on individual diodes within a photodiode array, allowing for the physical size necessary for the discrete photodiodes. Another use of the technique is to allow photodiodes to be located at locations where it is easy to pick up the electrical signals from them, depending on the location of other parts of circuitry on the chip.

Furthermore, all light from the dispersive arrays is directed onto the photo detectors. In the case of using output waveguides such as those marked 21 in Figure 1, some losses inevitably occur due to light which forms part of the output image but which is not conveyed through the waveguides due to the physical size and physical separation between adjacent waveguides in the output array. It is not possible for an array of waveguides side by side to detect the entire light forming the image of the output channels at position 20 in Figure 1. However, in the embodiments of the invention described above, the entire light output from the

array is directed onto the photodiodes thereby resulting in a much reduced loss of light intensity and light signal data which can be detected and used by the photodiodes in generating electrical signals indicating the result of signal demultiplexing.

The invention is not limited to the details of the foregoing examples. Although a single input waveguide is shown in Figures 2, 4 and 5, a plurality of input waveguides may be used. In that event, the input waveguides may be connected to respective light sources off chip and the ends of the input waveguides adjacent the dispersive array will terminate on an arc of the smaller Rowland circle with the point 17 lying in the mid point of that arc. The ends of the input waveguides will be inclined towards each other so as to point to the mid point of the facing ends of the dispersive waveguide array 11. When using a plurality of input waveguides 16, any one may be selected either by selective operation of light sources off chip or by including selectively operable attenuator switches on chip in the input waveguides 16.

The photodiode array 26 may be on chip or located off chip adjacent the edge of the demultiplexer chip 30. The photodiode may comprise a photodiode array or a plurality of separate photodiode chips located along the edge of chip 30.

CLAIMS:

1. An optical signal demultiplexer integrated on a planar substrate comprising a dispersive array of optical paths of different optical path length on the substrate, said demultiplexer having an input focal position at which light may be input to the array and an output focal line at which output signals representing the demultiplexed signals are focussed, the demultiplexer including:

a first set of reflectors located along the output focal line and arranged to respectively reflect each focussed output signal along a respective reflected path; and

a second set of reflectors arranged on the planar substrate, each reflector arranged in one of said reflected paths to reflect the reflected output signal incident thereon to a respective output location on the planar substrate.

2. A demultiplexer according to claim 1, in which the dispersive array is substantially symmetrical at opposite ends.

3. A demultiplexer according to claims 1 or 2, in which each of the reflectors in the first set of reflectors comprises a plane mirror.

4. A demultiplexer according to claim 3, wherein each reflector in the second set of reflectors comprises a convex mirror.

5. A demultiplexer according to claim 4, wherein the distance between the plane mirror and the convex mirror has a ratio of between 0.5 and 2.00 to the distance between the convex mirror and the output location.

6. A demultiplexer according to claim 5, wherein the convex mirror is located on each reflected path equidistant between the plane mirror for that output signal and the respective output location for that reflected path.

7. A demultiplexer according to any preceding claim, in which a plurality of light detectors are located respectively at the output locations.

8. A demultiplexer according to claim 7, in which the light detectors are located on the integrated planar substrate.

9. A demultiplexer according to claim 7 or 8, in which the light detectors comprise a line of photodiodes at one edge of the substrate.

10. A demultiplexer according to claim 8, wherein each photodiode has a width greater than the 3dB width of the Gaussian distribution of light in said output signals.

11. A demultiplexer according to claim 9 or 10, wherein the light detectors comprise two sets of photodiodes arranged along opposed edges of the substrate with a pitch selected to match the pitch of a multi-channel amplifier mounted adjacent the substrate.

12. A demultiplexer according to any of claims 10 or 11, wherein the outputs of the photodiodes are connected as differential pairs.

13. A demultiplexer according to claim 10, 11 or 12, wherein there are eight photodiodes.

14. A demultiplexer according to claim 7 or 8, in which the light detectors are located at spaced locations on the substrate.

15. A demultiplexer according to any preceding claim, in which the dispersive array comprises a plurality of optical waveguides.

16. A demultiplexer according to claim 15, in which the direction of the waveguides is inclined inwardly towards each other at the input end of the array

so that the directional axes of the waveguides at the input end intersect at the said input focal position.

17. A demultiplexer according to claim 16, in which a free light propagating region is provided on the substrate between the input end of the dispersive array and said input focal position.

18. A demultiplexer according to any of claims 15 to 17, in which the direction of the waveguides is inclined inwardly towards each other at the output end of the array so that the directional axes of the waveguides at the output end intersect at the output focal line.

19. A demultiplexer according to any of claims 15 to 18, in which a free light propagating region is provided between the output end of the dispersive array and said first set of reflectors.

20. A demultiplexer according to any one of the preceding claims, formed as an integrated chip.

21. A demultiplexer according to claim 20, comprising a plurality of silicon on insulator waveguides.

22. A demultiplexer according to claim 21, comprising a plurality of rib or ridge waveguides.

23. A demultiplexer substantially as hereinbefore described with reference to and as shown in Figures 2 to 5 of the accompanying drawings.

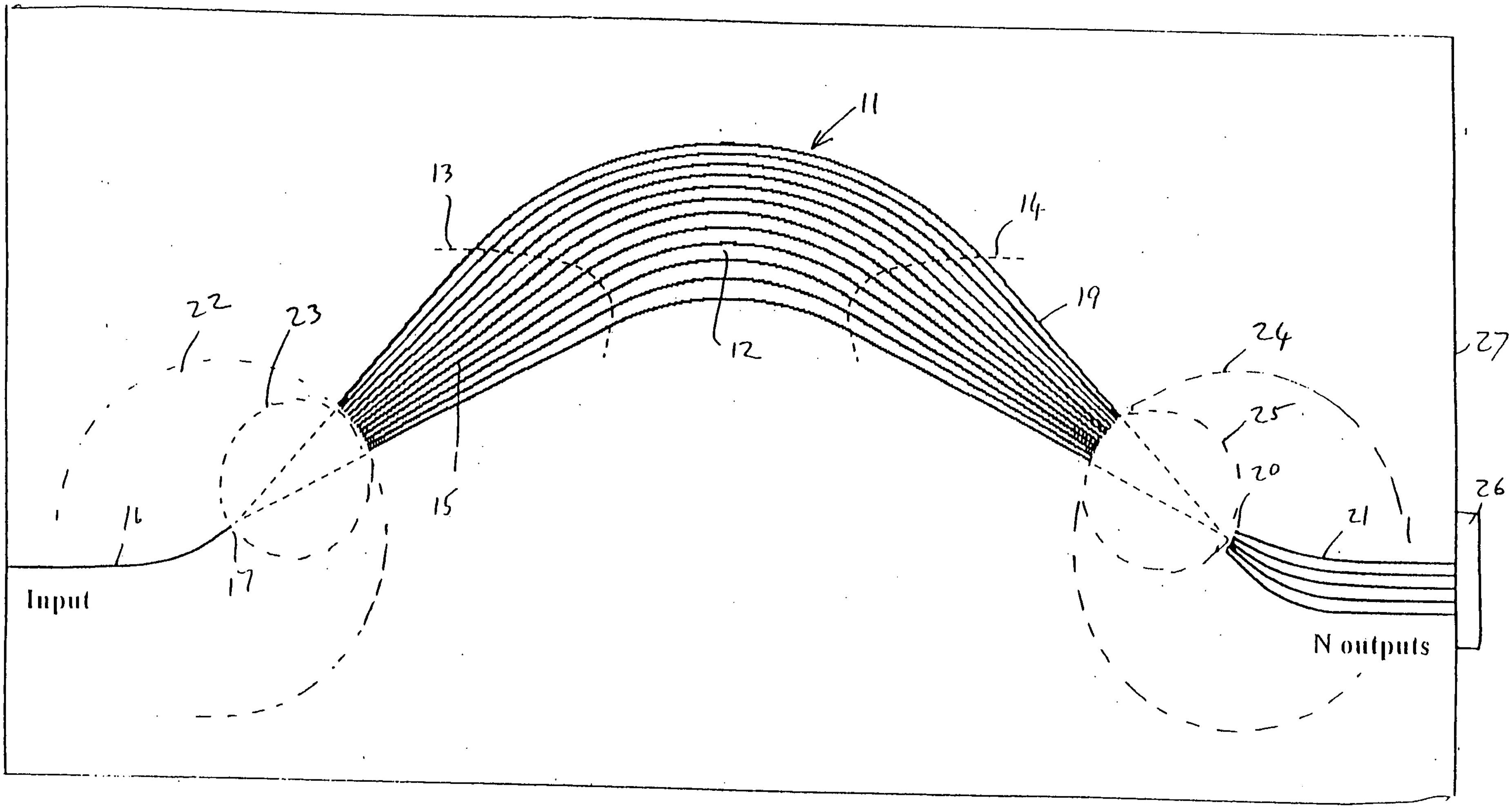
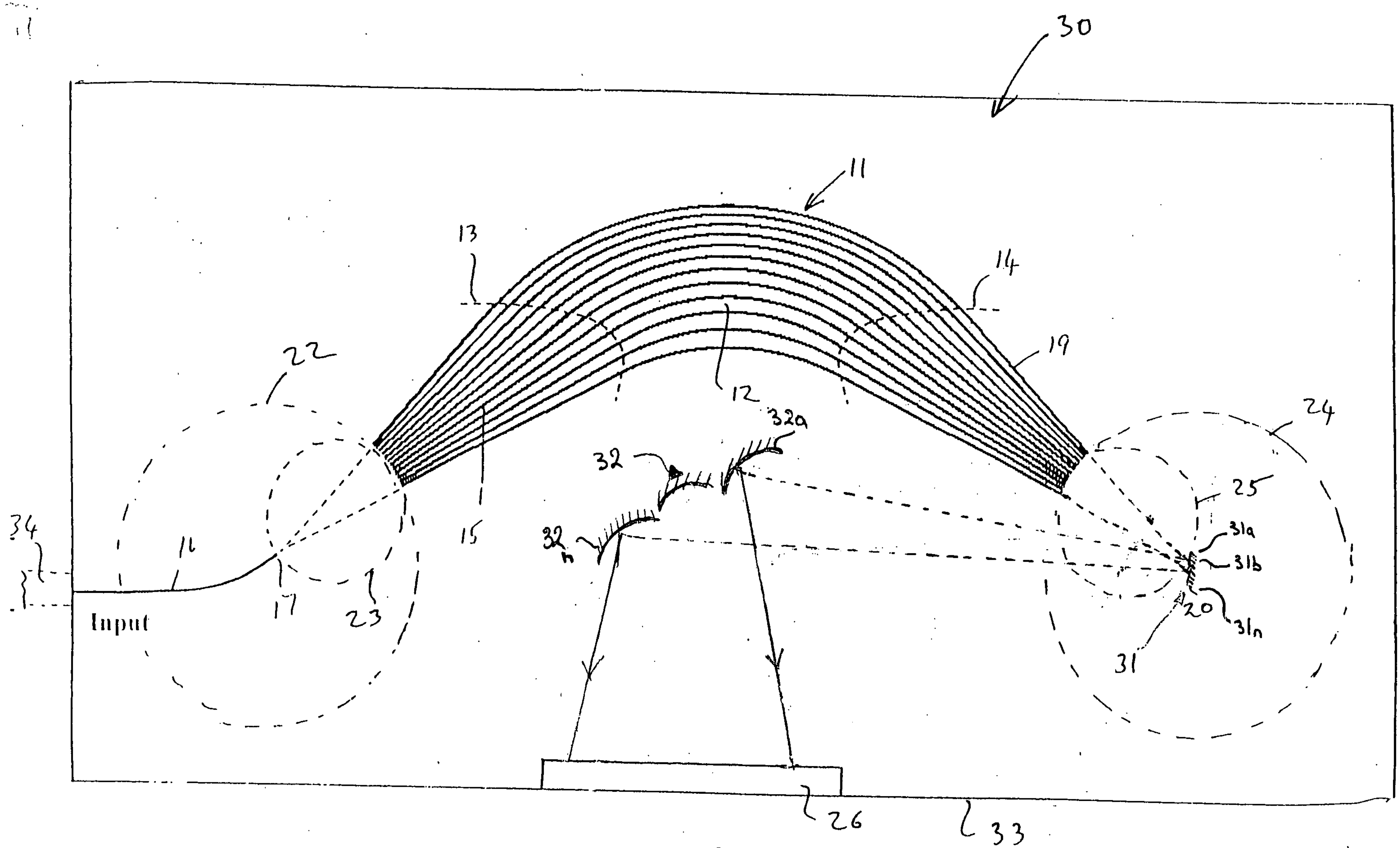


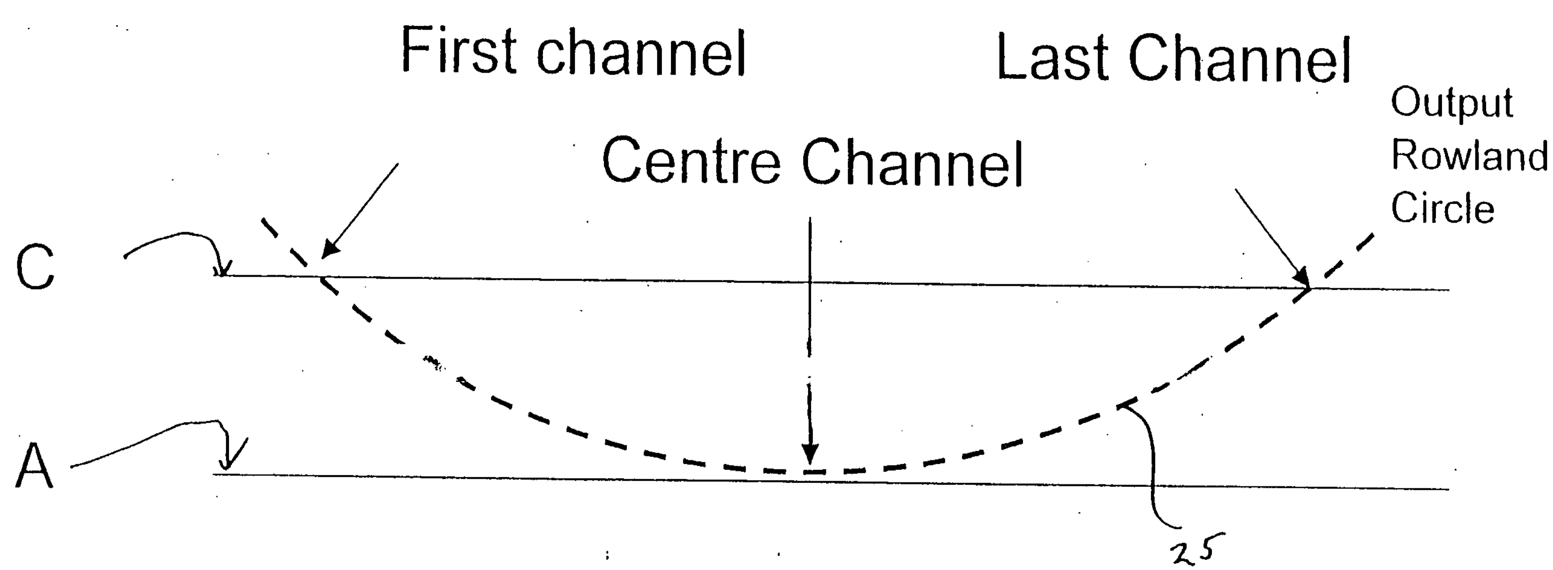
FIG 1 PRIOR ART



30
11
13
14
19
22
24
12
32a
32
25
15
34
16
32_n
31a
31b
17
Input
23
20
31n
31
26
33

FIG 2

FIG 3


First channel
Centre Channel
Last Channel
Output
Rowland
Circle
C
A
25

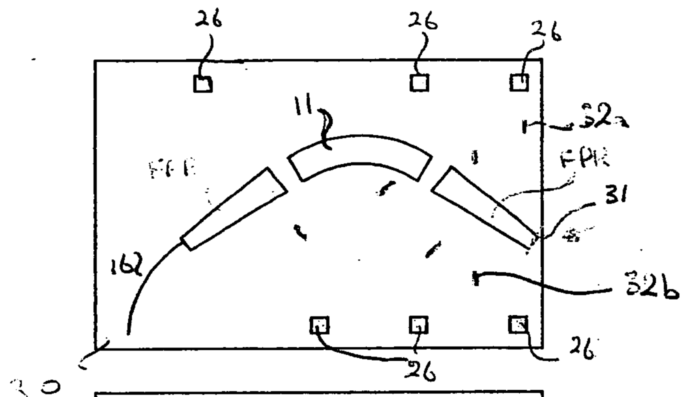


Figure 4

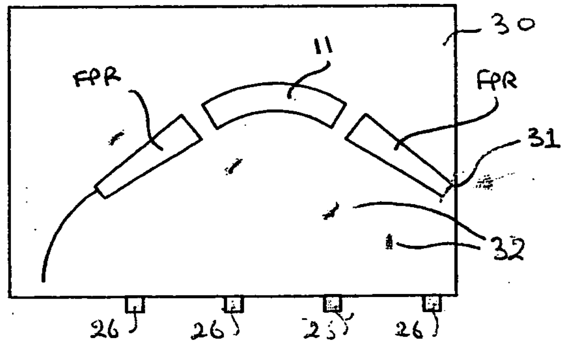


Figure 5